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A STUDY OF THE DATA COLLECTION, PROCESSING, AND  
MANAGEMENT SYSTEM FOR A WORLDWIDE SEISMIC NETWORK

BOLT BERANEK AND NEWMAN, INCORPORATED

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**FINAL REPORT**  
**A STUDY OF THE DATA COLLECTION, PROCESSING**  
**AND MANAGEMENT SYSTEM FOR A WORLDWIDE SEISMIC NETWORK**

14 September 1973

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13. ABSTRACT This report presents a recommendation by Bolt Beranek and Newman Inc. of a system design for a worldwide seismic data network. Particular attention has been paid to recent or imminent developments in the areas of digital communication, processing, and storage. Both sensor stations currently expected to be operational about 1975 and possible future expansion or modification of the network are considered. The major conclusions of the system design are (1) seismic event detection should be done at the array site in the majority of cases, (2) the ARPANET is generally a suitable and cost effective communication facility for seismic data transmission, (3) a communications control center should be established at SDAC in order to coordinate and monitor the seismic data network operation centrally, (4) network event processing can evolve from the existing large array event processing system at SDAC, (5) long period event processing should be done off-line using ARPANET computing resources with special consideration given to eventual use of the ILLIAC IV array processor, and (6) the Datacomputer service can provide an appropriate data management system for the seismic data network.			

KEY WORDS

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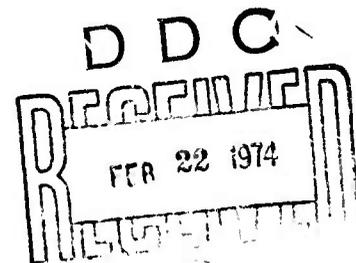
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**SUMMARY**

In a continuing program to provide high quality digital seismic data for research in detection and identification of contained nuclear explosions, ARPA plans to expand the existing digital seismic network to obtain more extensive worldwide coverage, particularly for long period data. Three additional small on-line digital arrays and 15 to 20 single point stations recording on digital magnetic tape are to be operational in 1975. The resulting seismic data collection network will produce a formidable library of valuable digital seismic data which must be organized and made available to the seismic research community.

Although this data collection network is not intended as an on-line surveillance system, an up-to-date epicenter list is essential for effectively accessing such a large, complex data base. The creation of an epicenter list requires extensive processing in addition to the computation tasks involved in the research program.

Several recent advances in the areas of digital communication and computer-related systems appear to offer new capabilities that may be applicable to the seismic data handling problem. Specifically, 1) the development of the ARPANET, a computer-controlled digital communication network, 2) the ILLIAC IV parallel array processor, and 3) the Unicon and TBM mass storage systems may be directly applicable to various phases of seismic data collection, processing, and storage.

Under the present contract, Bolt Beranek and Newman has prepared a recommendation of a system design for the worldwide seismic data network with particular attention paid to the possible application of these recent or impending developments in the digital processing and communication field. Background data for the design was provided by the VELA Seismological Center and the Seismic Data Working Group.

The major conclusions incorporated into the proposed system design are summarized in the following paragraphs:

- 1) With the present state of digital processing and communication technology it is most efficient to perform seismic array detection processing at the seismic station in the majority of cases.
- 2) The ARPANET is a suitable communication system for sending detection logs and selected data from the seismic field station to network event processing and storage centers. By using Very Distant Host protocol from the seismic station to the nearest ARPANET node, the seismic network can take advantage of future ARPANET expansion, use the ARPANET error control logic, and have the option of a variable data rate.
- 3) A seismic network control center should be established at SDAC. The functions of this control center will be to acquire, reformat, and distribute data from the network and to aid and interface with a network operator responsible for monitoring the network status and initiating maintenance and backup operations.
- 4) The existing large array event processing system at SDAC is a reasonable starting point for the evolution of a short period network event processing system. The

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processing capacity of the existing event processor seems adequate for the anticipated network event processing.

5) Long period event processing is essentially a variable load off-line function that can make use of ARPANET processing resources. In particular, the ILLIAC IV appears to be well suited to the long period array processing requirements in the 1975 era and the development of a long period event processing package for the ILLIAC IV should be initiated.

6) The Datacomputer service, with an appropriate tertiary storage, will provide a sophisticated large capacity data management system at a minimum cost to the seismic program. Accessibility of the Datacomputer service over the ARPANET insures that the seismic data library will be available to an expanding community of users with a minimum expense to each user for communication and equipment. A package of seismologically oriented retrieval programs available on one or more ARPANET server Hosts would greatly simplify access to the data base for seismologists.

## 1. INTRODUCTION

Under the VELA Uniform project ARPA has sponsored a research and development effort resulting in a major improvement in seismic sensor systems and in the sophistication of aid facilities for processing of the data from those systems. The objective of this research has been, and is, the development of the technical capability to detect small seismic events and to separate explosive and natural events based on their seismic signatures.

At the present time, the primary data for this research are digital tapes of 1) short period sensor array data from the Large Aperture Seismic Array (LASA) in Montana and the Norwegian Seismic Array (NORSAR), and 2) long period sensor array data from LASA, NORSAR, and the Alaskan Long Period Array (ALPA). These data are often augmented with digital data from other stations such as the Tonto Forest Seismic Observatory (TFSO).

In order to maintain an up-to-date catalog of seismic events to facilitate the use of the resulting data base and to aid in selection of data to be saved in the data base, detection processing and event analysis are performed on the short period data from LASA and NORSAR. The result of this routine analysis is a preliminary event list available within about 2 days of real-time. Users often augment this list with data from the Preliminary Determination of Epicenter (PDE) list.

The best criterion for the identification of explosive events is a combination of event depth and the ratio of the surface wave magnitude ( $M_s$ ) and body wave magnitude ( $m_b$ ). Use of the magnitude ratio requires that the short period body

waves and long period surface waves be detected for each event analyzed. With the existing sources of research data discussed above the detection threshold of short period body waves is significantly lower than that for the long period surface waves. In order to lower the long period threshold to that for short period data and to provide better azimuthal coverage for research involving multiple and overlapping events, ARPA plans to augment the primary data collection network to include at least three additional overseas stations.

In conjunction with the effort to expand the data collection network, ARPA is sponsoring a review of the communication, processing, and storage facilities for collection, analysis, and distribution of the data from the network and for preparing and disseminating the list of detected events.

Under the present contract, Bolt Beranek and Newman Inc. has been asked to prepare a system design for the worldwide seismic data network with particular attention paid to the possible application of recent or imminent state-of-the-art developments in digital communication, processing, and storage. This document is the final report of the system design study. In section 2 of this report we attempt to summarize the system requirements for the currently envisioned sensor network to be operational about 1975 and for possible future expansion or modification of that network. In section 3 we review the resources that are available for meeting the requirements. These include existing resources owned and operated by Vela, Vela-funded sites now owned and operated by other agencies or governments, and new state-of-the-art resources that may be applicable to the seismic network problem. In section 4 we present the system design for the 1975 system, including estimated costs, schedules and potential problem areas.

## 2. SYSTEM REQUIREMENTS

### 2.1 System Overview

It is assumed that the primary 1975 worldwide seismic data collection system will consist of the sites listed in Table I augmented by about 15 Seismic Research Observatory (SRO) and 10 Long Period Experiment (LPE) stations whose data will be recorded on digital magnetic tape and mailed to a system entry point.

Although this data collection network is not intended as an on-line surveillance system, an up-to-date epicenter list is almost essential for effectively using such a large seismic data base. It is, therefore, assumed that an initial event list will be prepared within a couple of days of real-time. The event list will at least include source time, source location, body wave magnitude, and Rayleigh Wave magnitude. The event list and at least some set of processed data will be available on-line to the user community. In addition, sensor data for at least some events or time periods will be available from the library either on-line or easily mounted on request.

The system design must account for 1) collection and formatting of digital data from the sites in Table I, 2) transmission of these data or some subset thereof to a central library via phone lines or mail, 3) processing the short period data from selected sites either at the site or at a central location to detect and locate tele-seismic events, 4) processing of long and short period data to estimate body and surface wave magnitudes of all detected events, and 5) storage and recall of the data generated in the previous steps.

Table I  
Seismic Network Data Sources

<u>Site</u>	<u>3 Component LP Sensors</u>	<u>Short Period Sensors</u>
Current LASA	17	345
Projected LASA	9	14*
NORSAR	22	132
ALPA	19	—
IRAN	7	—
KOREA	7	19
Site II	7	19
USO	1	3 (1 3-component)
SROs	1 each	3 each (1 3-compnent)
LPEs	1 each	—

---

\* 13 LASA sensors may actually be 13 small arrays with hard-wired averaging so that they appear as 13 sensors, one channel will be a low-gain signal for observing large events.

## 2.2 Site Processing, Communication and Storage

As shown in Table I, two of the array sites in the 1975 system are exclusively long period sites. Because of the large difference in data rates and processing requirements for long period and short period sites, the two classes of sites will be discussed separately.

### a) Long Period Sites

Since the present system philosophy allows long period processing to be done on an event basis after short period detection and location, there is no on-line processing required for long period data. The requirements for long period sites consist of digitizing and communication and/or recording relatively low rate data. Available communication link bandwidths are quantized to Teletype rates on the order of 100 bits per second, voice grade bandwidths from about 2 to 10 kc, and wider band circuits around 50 kc and higher. The data rates from the long period array stations are in the range of 300 to 1000 bits per second. The long period array data rates are, thus, too large for Teletype lines, but only a fraction of the available bandwidth of a voice grade circuit. Therefore, the major system problems are efficient use of communication bandwidth and provision for reasonable buffering and error control procedures to minimize the loss of data due to transmission errors and short duration circuit outages.

### b) Short Period Sites

In the 1975 system the primary short period stations include two very different groups. The first group consists of the two large arrays, LASA and NORSAR. The data rate from NORSAR is about 30 kc and the useful data rate from LASA at present appears

to be about the same, although the actual data rate from all the sensors in LASA is almost 200 kc. However, plans are being formulated to reconfigure the LASA to a much smaller sensor system. As shown in Table I, the LASA configuration for 1975 may be reduced to a data rate of about 2.3 to 2.4 kc. In the 1975 system the large array or arrays will control the detection threshold and, due to their large aperture, will provide starting locations for associating network detection times from the other stations. Efficient operation of the network requires near-real-time detection processing on the short period data from the primary short period arrays. The processing for the large arrays should cover all likely source regions such as seismically active zones and known test sites. The detection processing load for each of the large arrays essentially uses more than the total capacity of a large configuration of a 360/40. Both large arrays now have associated detection processors, and all data from the large arrays is recorded on digital magnetic tape by the detection processors. An existing 2400-bit-per-second communication circuit transmits the NORSAR detection list, long period data, and selected short period data to the LASA detection processor.

The second group of short period sites for the 1975 system consists of 2 small arrays with data rates on the order of 4 to 10 kc (i.e., well conditioned voice grade circuits). For the 1975 system, the effect of these small arrays on the network detection threshold will be important only for selected regions from 20 to 40 degrees from these 2 small arrays. Thus, most of the improvement in network detection from the small arrays could be realized with 10 to 15 beams from each array. The present plans are to include a station processor at each of the small arrays in the 1975 system. The station processors are capable of detection on about 16 beams and of connecting to a 4.8 kc

communication circuit. This communication capability will be used to transmit the detection list, the data from long period instruments at the site, and possibly selected short period channels or beams. The raw data can be recorded on magnetic tape by the station processor.

The reconfigured version of LASA will probably have a detection capability similar to the small arrays, but the larger aperture will provide a better localization capability for those events that it detects. In order to use the localization capability for the detected events outside the coverage of NORSAR, the LASA processing should include beams covering at least all seismically active teleseismic regions.

Additional sites that must be considered for the 1975 system are the approximately 15 SRO sites, 10 LPE sites, and 1 USO site. Short period and long period data from the SRO and LPE sites will be recorded on tape at the site. The tapes will be mailed to a central location where quality control and tape duplication will be performed. A copy of the tapes will then be available to the network processing and storage system. Data from the USO site will enter the system by satellite communication from a small ground terminal at the site.

In addition to the network requirements for handling the data from the foreign stations, the local owner/operator organizations (e.g., local university seismologists) will impose requirements for data recording and analysis. Local communication regulations and capabilities will place further constraints on the site configurations. Because of these various local requirements and constraints, the system configuration must be flexible enough to accommodate a variety of site configurations.

## 2.2 System Processing Requirements

### 2.3.1 Detection Processing

Detection processing is done only on short period data in the present design. The processing required for a short period array consists of beamforming, filtering each beam, integration of the output power over a short and a long window, and a test to see whether the ratio of the powers in the two windows is outside preset limits. Experience has shown that for optimal beamforming gain the minimum sensor spacing should be 3 km or more. The maximum spacing is controlled by the homogeneity of the crust and upper mantle in the region of the array. The number of beams that have to be formed from an array is determined by the maximum sensor spacing in the array. In practice, the number of beams required for both large arrays and small arrays has usually been in the range of one to three times the number of sensors. Due to the large spacing between the effective sensor locations in the reconfigured LASA, the number of beams for complete teleseismic coverage from that array is more likely to be 10 to 30 times the number of sensors.

Each of the primary short period arrays in the 1975 system will, at least initially, have a detection processing capability local to or associated with the array. The detection processing capability associated with the small arrays, however, will only be capable of forming about 1/3 of the optimal number of beams for the array. This level of detection processing is considered adequate for the objectives of the 1975 system. Although it may eventually be more efficient for the entire network to perform all the detection processing at a central specialized

computer center, the detection processing for each array in the 1975 system would probably continue to be done locally except for LASA detection processing. If more short period arrays are added to the network or if optimal use of the original small arrays in the system becomes necessary, then additional detection processing capability will be required.

### 2.3.2 Off-line Processing Requirements

The objective of the off-line processing for the network will be to generate a list of the events seen by the network and summary descriptions of each event. The event list will include source time, location, body wave magnitude ( $m_b$ ), and Rayleigh wave magnitude ( $M_s$ ) for each event detected by a large array or by more than two stations.

The required processing includes 1) associating detections from the short period stations, 2) computing event location from associated detection times, 3) computing the "best" short period waveform (beam) for each array site from whatever data is available, 4) measuring amplitude and period and computing  $m_b$  from the best SP waveform from each site, 5) computing the best long period waveform for each long period station, and 6) measuring Rayleigh wave magnitude for each station.

The computation load associated with grouping or association of detection times from the network can be greatly reduced by taking advantage of rough event locations from the large arrays. Previous experience with association of network times by computer when only arrival times are available is, therefore, of dubious value for estimating processing load.

Since the off-line processing is done by event, the number of detected events a day controls the total off-line processing load. Day-to-day, the number of detected events can vary by a factor of five or more in extreme cases.

Another characteristic of event processing, particularly for a network of stations, is that it often requires the judgment of an analyst to control and interpret the processing operations. This is particularly true for small, emergent, or overlapping events. The analyst can also recognize and account for such effects as variations in propagation paths, directional variation in characteristics of the source radiation, and data from sources near the receiver such as local earthquakes and impulsive noise sources. Interaction between the analyst and the event processing is greatly enhanced by graphic output on a CRT or chart recorder. The analyst should have a great deal of flexibility in what he looks at and the scaling and alignment of the output.

### 2.3.3 Processing SRO, LPE, and US) Data

The processing of data from the Seismic Research Observatories (SRO) could be considered a part of the off-line processing. The major contribution from SRO data will be additional arrival times to improve the network event location capability. The most useful measurements from the SRO data will, therefore, be detection times for events already detected by the primary stations. Since there is only one SP instrument at each SRO, detection processing consists of filtering, integrating the power over two windows, and computing the ratio of the power in the two windows. After searching the SRO detection lists for

arrivals associated with previously known events, the residual detection times may be added to a list of unassociated times from the primary stations and another attempt made to group the unassociated times to find new events. For this pass through the detection time list there will be no preliminary large array locations. Previous experience in preparing event lists from unassociated times is valid for this pass, and that experience indicates that the processing load is large for the few additional events that will be found. Since the additional events are not likely to be of much interest for the discrimination problem, it seems reasonable that this processing should only be performed for selected experimental periods during which the maximum detection capability of the network is of interest.

The SRO processing will also include the measurement of short and long period magnitudes for network events detected on the SRO data. For these measurements, the SRO waveforms will be treated the same as the best SP and LP beams from an array site. The load placed on the system by the SRO processing will include a small constant detection processing load plus a highly varying analysis load depending on the number of detected events and on particular network experiments that may be conducted.

The LPE stations have only one extended frequency 3-component set of long period instruments at each station. They will provide additional long-period magnitude estimates for some events. The processing load from these sites will be small.

The USO station is primarily an experiment in operation of an unmanned station. Because of the ocean noise and the large number of local events, routine processing of data from the station for a contribution to network detection and location will not be very productive. In any case, the implied processing load would be small.

## 2.4 Data Storage Requirements

For this discussion there are essentially 4 classes of data generated by the network. These include SP sensor data, LP sensor data, processed waveform data, and processed alpha-numeric data.

The short period sensor data from the primary network sites represent about 95% of the total seismic data generated. After detection processing, on the order of 10% of that data may be used for forming the best beams from each array site for event analysis (assuming about 50 events per day and 2 minutes per event) of detected events. Probably 10% or less of the processed events will be of sufficient interest that further reference will ever be made to the SP sensor data. Thus, on the order of 2% (certainly less than 5%) of the sensor data will ever be used after initial event processing. Data of interest to one user are often of interest to a wide community of users, so that while the chance that anyone will be interested in any random sample of SP sensor data is small, the chance that a second user will be interested in the data once used is much greater. On the other hand, the cost of transmitting and storing the SP sensor data is very large.

The LP sensor data represent a much smaller total volume of data. Since the LP surfacewave propagation is dispersive, a single event is usually spread over 10 to 20 minutes of data. As a result, over half of the LP data is required for event processing and 10% or more will be used again after event processing. Due to the spreading of LP energy, the likelihood of events overlapping in LP data is much higher than for SP data and optimal use of the LP arrays is therefore more important than for SP processing.

Thus, although most of the cost for transmitting and saving all sensor data would go into SP data, most of the sensor data used would be LP data.

Processed waveform data for this network consist of LP and SP "best beams" for each event. In principle, if all sensor data covering event arrivals were saved then the choice of storing or regenerating these waveforms could be based on the trade-off between processing cost and storage space. The choice could be invisible to the user. If the sensor data for all events are not saved, then waveform data from the beams or sensors used for magnitude measurements for the network event list are valuable to users who want to make measurements other than magnitudes (e.g., complexity, spectral ratios, etc.) and to users who want to verify the system performance.

The processed alphanumeric data consist of the network event list including at least source time, source location, depth estimate,  $m_b$  and  $M_s$  for located events, and signal descriptions (arrival time, amplitude, period, and possibly estimated azimuth and velocity) for events not located but detected at some site with sufficient signal level that reliable measurements can be made.

A user accessing the file system will normally begin by reviewing the alphanumeric file to find a list of events of interest for his application. He may then look at associated processed waveform data for the selected events, and finally may look at sensor data for a few events of particular interest. Users interested in waveform data will often want standard transformations performed on the sensor or beam waveform data as a first step in their analysis.

Another broad class of users will enter the system with the question, "Did any network station see an event occurring at a particular place and time?" or, "What data is available from the network corresponding to the expected arrival time of an event at a particular time and location?" When using array data, the user will want to form a beam optimized for the hypothesized source.

Thus, a smart retrieval system with the power to compute arrival time from source time and location and to compute various routine transformations on waveform data would save users considerable inconvenience and would reduce the duplication of effort required for each user to write his own programs for these computations.

### 3. RESOURCES AND STATUS

#### 3.1 Existing VELA Computer Resources

##### SDAC

SDAC, in Alexandria, Virginia, has resources both for recording and processing of LASA, NORSAR, and ALPA data and for conducting seismic research. The on-line system at SDAC requires dedicated use of a Special Processing System (SPS) and an IBM 360/40 computer for detection processing of LASA data. A second IBM 360/40 is being used for event processing and is loaded slightly over two shifts per day at present.

The 360/40s each have 256K bytes of core memory and assorted peripherals including a card reader/punch, high speed line printer, 2311 disk units, and a number of tape drives. Each 360/40 has been augmented by a sum-of-products hardware unit (which contains an 8 x 8 multiplier and adder matrix, several registers, partial results adders and miscellaneous control logic) and special micro-programmed instructions to carry out the operations of beamforming, recursive filtering, convolution filtering, and rectify/integrate. The SPS, in addition to its function as a communications interface for the detection processor, is also micro-programmed to do subarray beamforming and filtering.

A Digital Equipment Corporation (DEC) PDP-15 system and an IBM 360/44 machine are also available at SDAC. Although the PDP-15 is used primarily to provide interactive graphics associated with seismic research, some background scientific batch and support of utility functions (e.g., tape-to-tape, card-to-tape, plotting) exist as well.

The PDP-15 has 64K of core memory and the VT15 graphic display console. In addition it has a large collection of peripherals, including fixed and moving head disks, DEC tapes, 7 and 9 track magtapes, a card reader, a line printer, a Calcomp plotter, a Varian electrostatic printer/plotter, and an A/D converter. The PDP-15 runs under the DEC RSX real-time operating system and is expected to be heavily loaded supporting the above mentioned tasks.

The off-line 360/44 is being used primarily for research computations. Much of this is related to long-period data processing necessary to add surface wave data to the LASA station bulletin. Studies are being carried out by Teledyne Geotech and Texas Instruments in this area.

The 360/44 has 384K bytes of memory and assorted peripherals including a reader/punch, a printer, the Calcomp equivalent of 3 2314 disk units, and a number of 7 and 9 track tape drives. The 360/44 runs DOS-GRASP 24 hrs/day, 7 days/week to service the previously mentioned load. This 360/44 also provides SDAC access into the ARPA Network. All of the equipment at SDAC is purchased.

#### LDC

There are two computers at the LASA Data Center (LDC) in Billings, Montana. A stripped IBM 360/44 computer is used for data editing and computation prior to transmission over the 50Kb line to SDAC. A DEC PDP-7 is used for array control and for backup recording of the array data in case the 360/44 or the phone line is inoperative. Neither of these machines is currently

available. The 360/44 has only 131K bytes of core, and a card reader, plus required data acquisition and communication equipment. In addition, the processing unit lacks a number of useful features including a floating point processor. The PDP-7 has 16K of memory and 4 tape drives.

### NDPC

Similar to the on-line system at SDAC, the on-line system at NDPC requires dedicated use of a Special Processing System (SPS) and an IBM 360/40 computer for detection processing. As at SDAC, the two 360/40s at NDPC have been enhanced by sum-of-products units and both the 360/40s and the SPS have been micro-programmed to speed up the operations of beamforming and filtering. The second 360/40 at NDPC is being used for both event processing and seismic research computations. The computer resources at NDPC are totally committed with their current load.

## 3.2 ARPANET and Connected Computing Resources

### 3.2.1 ARPANET Communications

The ARPA Network [1, 2] provides a flexible, reliable, and economically attractive means for dissimilar, geographically distributed computers (Hosts) to communicate via common-carrier circuits. Each Host connects into the network through a small local computer called an Interface Message Processor (IMP); each IMP is connected to several other IMPs via wideband (typically 50 kilobit) communication lines. The IMPs, all of which are virtually identical, are programmed to store and forward messages to their neighbors based on address information contained in

each received message. The route that a message will take through the network between its source and destination is not fixed in advance but is determined dynamically to take into account network loading as well as IMP and line failures. Terminal IMPs (TIPs) provide a mechanism for connecting terminals directly to the network without the need of an intervening Host computer.

The ARPA Network has been in operation for over 4 years and considerable experience regarding its use has been accumulated. There are currently some 40 computers of about 20 different types connected in a 40-node multiply-connected net. The network has been in a continual state of expansion as additional research centers and government agencies have initiated use of the network. As befits the growing operational character of the ARPANET, ARPA is making efforts to transfer the network from under ARPA's research and development auspices to an operational agency or specialized common carrier of some sort.

Aside from a continued growth in the number of network nodes and level of network activity, there have been a number of technical improvements which are at various stages of becoming operational. Arrangements have been made to allow Host-IMP connections at large distances over common-carrier circuits, the Very Distant Host (VDH) connection. A significant extension of the network began in January 1973 with the establishment of a satellite link to Hawaii; a similar link to Europe was added in August. Work is proceeding on the development of techniques for efficiently sharing a satellite's channel capacity. Another current activity is the provision to allow connection of remote-

job-entry terminals to an IMP. Finally, a major effort is under way to design a new "high speed modular IMP", HSMIMP, based on a minicomputer/multiprocessor that will be capable of operating at megabaud data rates, or of providing a low cost connection into the net for lower rate service.

### 3.2.2 Special Purpose Computing Facilities

The ARPA Network provides a means of making specialized one-of-a-kind systems available and a large user community over which to amortize the cost of such major resources. Currently, one such resource of particular interest to the members of the seismic data processing community is the large parallel processor, ILLIAC IV [3, 4], located at the Institute for Advanced Computation at the NASA Ames Research Center. The operations of beamforming, digital filtering, and rectify/integrate on a large number of short period beams which are basic to the detection of seismic events appear well suited to a large array processor. It makes sense to consider using the ILLIAC IV for processing long period seismic data as well.

The ILLIAC IV array consists of a single master control unit (CU) that sends instructions to 64 independent processing elements (PEs) and sends addresses to individual memory units (PEMs) associated with these PEs. Although a single sequence of instructions controls the operation of the entire array, each PE generally carries out the operation on different data. Each PE is a powerful computer in its own right with a wide range of arithmetic and logical operations. Each PEM has 2K 64-bit words with an access time of roughly 350 ns. The time required to do 64 parallel adds is less than a microsecond. Special routing instructions exist to move data from PEM to PEM.

This architecture permits highly parallel execution of detection processing and data reduction algorithms. Initial estimates indicate that the time required to process SP sensor data from the current LASA array using direct (rather than two-stage) beamforming and existing algorithms for filtering and rectify/integrate/threshold would be on the order of 1 second of ILLIAC IV time for 60 seconds worth of data. This would require, of course, the facility to buffer on the order of 2 megabits of data accumulated over a 60 second period. For a typical small seismic array, perhaps forming 40 beams from 25 short period sensors, both the ILLIAC array time and the required buffer space would be significantly reduced.

The ILLIAC IV array processor is only one part of a sophisticated computer complex at NASA Ames. It is important to consider its part in this complex. The system which is planned in the near future is a star configuration around a large (500 K words) central memory. Connected to the central memory will be a swapping drum, the modified Precision Instruments Unicon Mass Store ( $10^{12}$  bits), the ILLIAC IV array processor and its associated disk ( $10^9$  bits,  $10^9$  bits/second), a Burroughs B6700, and a number of TENEX PDP-10 systems (currently 1). The TENEX systems are to provide overall control of the system and are to be connected as Hosts to the ARPA Network. In order to use the ILLIAC IV array processor in real-time, seismic data would have to flow in from the ARPANET, through a TENEX system and central memory, and out onto the ILLIAC disk where it would be accumulated waiting for its turn to use the ILLIAC IV array. These data could also be archived on the Unicon if desired.

The status of the ILLIAC IV system is best described as minimally operational. As indicated above, not all of the hardware has been delivered, let alone working. In particular, the central memory is not scheduled for delivery until December 1973. The PEs and CU have continued to have reliability problems, although this situation seems to be improving. Although software to provide batch access to the ILLIAC array is currently being developed, there does not appear to be any work in progress to make the system capable of guaranteeing a user a fixed fraction of real-time as required by the detection processing algorithms mentioned earlier. Development of this type of real-time service will apparently wait until the batch service can be provided reliably. Both the development of a real-time monitor and a substantial improvement in total system reliability will be required before it becomes feasible to do on-line detection processing at Ames. Processing long period data in the batch mode, however, may be something which can be attempted much sooner.

Nothing is firm at this time with regard to the cost of ILLIAC IV service. However, as a very rough estimate one can take the annual ILLIAC IV budget of \$10,000,000 and assuming 4000 hours of available time per year come up with an operating cost to ARPA of \$2500/hour.

### 3.2.3 General Purpose Computing Facilities

Aside from providing general access to one-of-a-kind computer resources, the ARPA Network provides a convenient way of communicating with general purpose batch and time-sharing computers. These resources will probably be of interest to many seismic researchers as sites for program development. One such

site, the UCLA-360/91, is already being used to develop algorithms for long period processing. Although there are a large number of machines connected to the ARPANET, not all of the servers have sufficient excess capacity to permit more than a minimal amount of network load. Nevertheless, there currently exist a significant number of resources available for general purpose computing. The available batch servers include the UCSB 360/75, the UCSD B6700, and the UCLA 360/91. The available timesharing servers include the Ames 360/67 (TSS), the MIT MULTICS system, and the TENEX systems at BBN, CASE, CCA, and USC-ISI.

#### 3.2.4 Mass Storage Facilities

By the end of 1975, it has been estimated that the seismic community will require approximately  $4.4 \times 10^{11}$  bits of on-line storage [5]. This will consist of both sensor and processed long and short period data. The figure could be slightly higher if all SP sensor data were stored for the reconfigured LASA. One of the few devices capable of providing this type of service is the Precision Instruments Unicon 690 [6] which is part of the ILLIAC IV system complex at NASA Ames.

The Unicon was delivered with a laser recorder unit and recorder control unit built around a Hewlett-Packard 2116B and two Word Processors. The recorder control unit is currently being redesigned by the people at Ames and one estimate as to when the Unicon will be operational is mid-1974.

The laser recorder unit reads and writes the actual data. Writing is accomplished by burning small holes in a thin film of metal on a polyester sheet with a laser. The laser recorder unit is a write-once device in the sense that zeros can be changed to

ones, but not vice versa. Reading is accomplished by sensing variation in the light reflected back from the data strip. There are 450 strips in the on-line file system, any one of which can be automatically mounted on a drum for reading or writing in less than 9 seconds. Each strip stores approximately  $2.2 \times 10^9$  bits. The on-line storage of  $10^{12}$  bits is roughly the equivalent of 10,000 standard 800 bpi 2400 ft. magnetic tapes.

The cost of a complete Unicon such as the one being constructed at Ames is estimated to be \$1,000,000. The cost of off-line storage for the Unicon is \$15/strip (\$10 in quantity) giving a cost/megabit of \$0.0068 (\$0.0045).

A device such as the Unicon is not suitable for use by most users without a considerable amount of support software. The Computer Corporation of America (CCA) has been developing this software under the Datacomputer Project. The Datacomputer is a system which performs the functions of data storage and data management. It is designed to be relatively device-independent but is oriented toward operation on a tertiary ( $10^{12}$  bit) store.

The Datacomputer may be viewed as a black box having multiple ports to which external processors are interfaced. A standard notation called Datalanguage provides a uniform method for interaction between the external processors and the Datacomputer (data base).

The types of services available and planned are the following: (1) On-line storage of files and file descriptions, (2) Retrieval of data including whole files, subsets of files, individual elements, and multi-key Boolean requests, (3) File maintenance such as addition, deletion, and modification of data, (4) Data

reformatting including conversion among character sets, number representations, and file formats, (5) Backup and recovery mechanisms, (6) Accounting for user charges, (7) Data security monitoring, that is, preventing unauthorized data accesses, and (9) Control and synchronization of multi-user access.

Because it exists and has the type of facilities which will be required for maintenance of seismic data files, the Datacomputer seems an appropriate device to use. An initial version of Datalanguage (0/9) [7] has been implemented and is running on the TENEX system at CCA. The Datacomputer can run on the TENEX system at CCA and may eventually be moved to utilize the tertiary store at Ames.

### 3.3 Signal Processing Hardware

During the past five years, a number of manufacturers have developed and begun marketing special purpose hardware designed specifically for digital signal processing [8, 9, 10]. Signal processing hardware may operate either as a stand-alone unit or as a peripheral processor to a local Host computer. Typical functions performed by these processors include Fast Fourier Transform (FFT), convolution, correlation, and recursive filtering. The internal control of the units can be either totally hard-wired, microprogrammable, or handled via conventional software. Speed is achieved through the use of high speed logic, scratch pad memories, and a parallel architecture (multiple arithmetic units) which has been optimized for signal processing operations. Typical sizes for operands are 16 bits for fixed point and 32 bits for floating point although there is considerable variation here. Register to register fixed point addition times are on the order of 125-500 nsec.

The signal processors described above appear to be well suited to the task of real-time seismic event detection. Even a relatively inexpensive unit, costing on the order of \$35,000, would have the computational power to take on essentially all of the subarray beamforming, array beamforming, filtering, and rectify/integrate/threshold load currently associated with LASA event detection. Such a unit would require a Host computer to control it with sufficient memory to buffer the input data, subarray beams, and array beams in addition to programs and data constants. This type of signal processor would be appropriate to consider for locating at future sources of short period seismic data in order to do local detection processing. A mini-computer (such as a PDP-11) could support the signal processor at a typical small site generating 40 beams from 25 seismometers.

#### 4. 1975 SYSTEM DESIGN

##### 4.1 Background and Organization

The worldwide seismic data collection system to be operating in early 1975 is basically an extension of an existing data collection activity. Some of the sites and processing facilities already exist. Several of the sites are or will be owned and operated by foreign organizations or governments. The existing facilities and the requirements and preferences of the local owner/operators constrain the possible configurations for the system. In addition, the objective of having the network operating by early 1975 limits the introduction of major new technology in the initial implementation.

As a result of these constraints and a desire to keep costs within reasonable cost-effective limits, this design attempts to specifically address the new problems introduced by the expanded network. These problems include communications with a worldwide distribution of sites and communication among processing and storage resources; the additional short period event processing load to compute network locations and body wave magnitudes; the additional LP processing load to optimally process LP data in order to lower the threshold for surface wave magnitude measurement; and, finally, the need for a data storage and retrieval system that has the potential for making the data more widely accessible and reducing the load on the SDAC processing facilities and personnel. Because the added SP arrays will include a limited on-line detection capability and the SP detection threshold is not the limiting factor in the current research effort, there is only a negligible increase in the detection processing load.

For those cases in which impending technical developments could significantly benefit the system but cannot be relied on in time for initial operation of the system, an option allowing transition at a later time with minimum cost and disruption will be identified.

The system description will start with a summary of the major features of the system. Each of four major subsystems will then be discussed in more detail. These subsystems include 1) data acquisition (by seismic station); 2) communication and control processor; 3) event list computation; and 4) file storage and retrieval. Under each subsystem we will describe the recommended configuration, costs, schedules, and finally the major problems or bottlenecks and possible longer range solutions.

#### 4.2 System Summary

Figure 1 shows an overall block diagram of the proposed system. Data enter the system from the seismic field stations by mailed magnetic tape, ARPANET, or leased lines. The primary entry point into the system is at the SDAC. One possible exception may be taped data from the SRO stations which may eventually enter the ARPANET at the NOAA laboratory at Albuquerque and be routed to the archival store.

The general approach in this system is to perform detection processing at the seismic station. This approach has three advantages for the 1975 system. First, all of the SP array stations except LASA have or will have local detection processing capability to meet local owner/operator requirements. Second, digital processing capability is cheap and reliable using present technology, while long distance wide-band communication is still

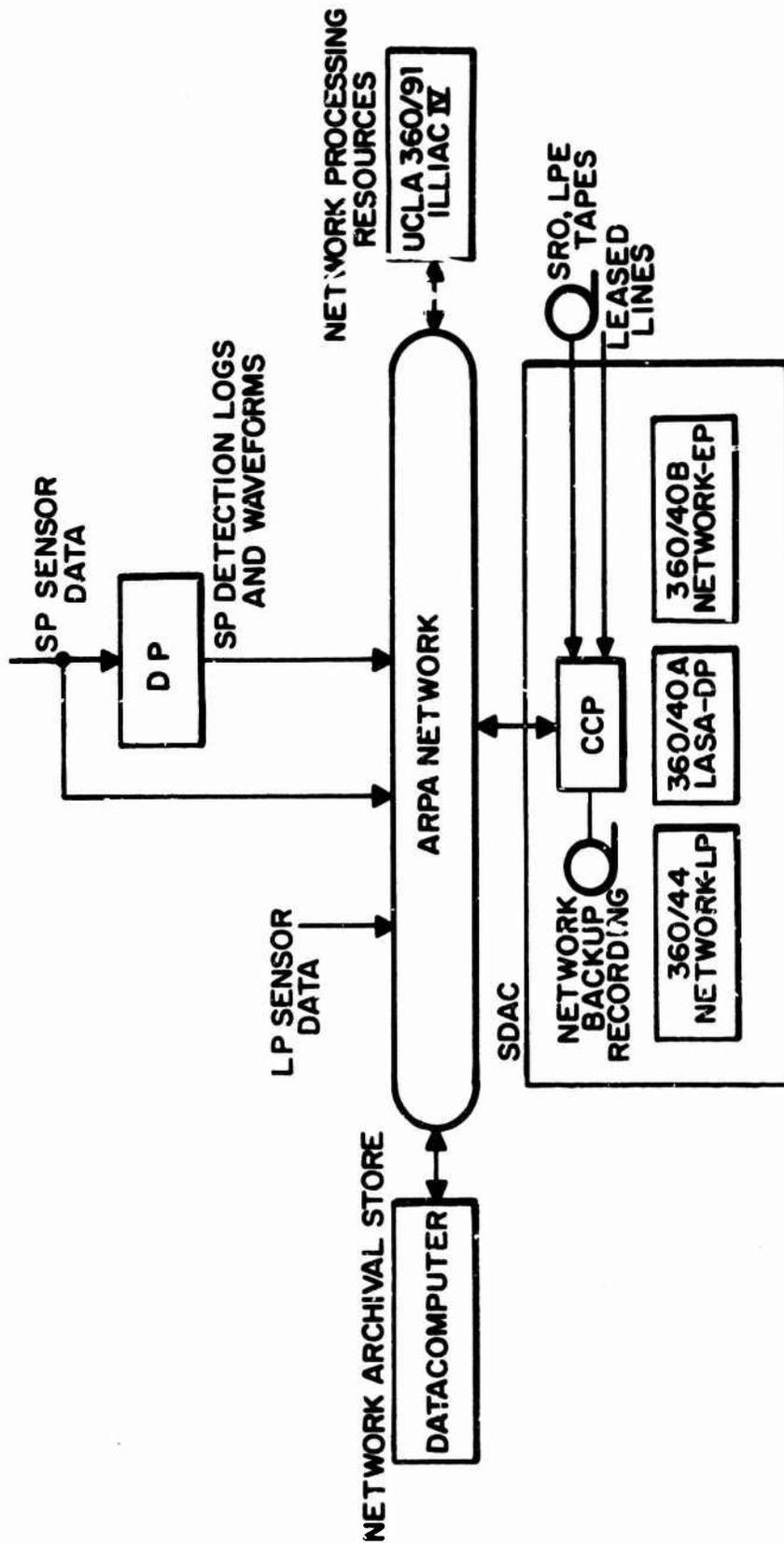


Figure 1 System Overview

expensive, so that the cost balance favors reducing communication bandwidth by performing local data reduction. Finally, dispersing the detection processing (which is basically an on-line real-time operation) reduces the vulnerability of the system operation so that a single computer failure cannot cause the entire network to fail or overload at the data input buffer level.

The single possible exception to field detection processing for the SP array sites is the LASA. LASA detection processing is now done at SDAC. Since this is a working system, the operation should be changed only for very compelling reasons. If the configuration of LASA is changed drastically, however, the question of detection processing location should be reviewed. We have considered the proposal to reduce LASA to the equivalent of 13 normal gain and one low gain short period sensors. This configuration would result in an unusual array with a large diameter for the number of sensors. If the optimum gain and localization capability of this system is to be realized, detection processing will be a signal-expanding instead of a signal-reducing operation. The detection processing for this configuration would be closely compatible with the existing DP programs in the 360/40A. We therefore believe the detection processing should continue to be performed at SDAC for this particular proposed reconfiguration.

The communication and control processor (CCP) located at the SDAC provides for routing of information entering the system, the control of data flow within the system, and control of magnetic tape backup for the archival storage facility. It also provides a central, flexible termination for the various types of communication protocols on ARPANET or leased communications circuits from the sites.

The short period event processing in this configuration is performed in one or both 360/40s at SDAC. Event processing programs already exist for these machines and the analysts have experience using the EOC which provides interactive access and control for the processing.

The long period processing in this configuration is performed primarily using ARPANET processing resources under control of the SDAC analyst. Some LP processing may still be done at SDAC; in particular, the LPE and SRO processing may be done as part of the procedure for entry of that data into the system. Use of ARPANET resources for expanding LP processing capability is an extension of the present effort to use the 360/91 for f-k processing and anticipates the possible use of the ILLIAC IV for this load (see Section 4.5.2).

Finally, the storage and retrieval system proposed uses the Datacomputer service for primary on-line and off-line archival storage. This system has the advantage of flexibility in choice and timing in choosing the specific storage location (Ames or CCA) to be used for the seismic data. It also makes use of a major software development already being funded by ARPA rather than developing a new data management system. The consideration of a seismically oriented front end to interface the seismologist with the Datacomputer system is suggested.

A basic technical problem results from the decision to perform detection processing at the seismic field stations. Although there does not appear to be an urgent need for lowering the short period detection threshold, there is certainly a need for a reliable estimate of the body wave magnitude ( $m_b$ ) of each detected event. An estimate of  $m_b$  based on measurements at a network of stations distributed in range and azimuth around the source event is

significantly more reliable than a single site measurement because of the effects of source radiation pattern and propagation path. Thus, a near optimum (or at least a good signal to noise level) waveform from each of the short period stations detecting the event is needed for estimating  $m_b$ . Both the responsibility of the SDAC analyst for the accuracy of the event list and good scientific practice of making the source data backing published measurements available require that the waveforms used for estimating  $m_b$  be available at SDAC and in the data base (or be able to be recomputed from the data base) rather than making  $m_b$  measurements at the station and discarding the waveform used.

If detection processing is to be performed at the seismic field station so that sensor data do not have to be transmitted to a central location, then some provision should be made for saving and transmitting appropriate waveform data for each detected event. For small arrays, two to five minutes of unfiltered data from the beam with maximum detected amplitude starting about 30 seconds before detection should suffice. For large arrays, the suggestion that the best subarray beams (those used in the array beam on which the event was detected with maximum amplitude) should be transmitted seems reasonable since that would allow final adjustment of the delay times used in forming the optimal array beam. A waveform from at least one sensor from each site should be saved.

#### 4.3 Data Acquisition

This section describes the configuration of the contemplated on-line reporting sites. For each location the local sensing equipment, processing subsystem and communications equipment are discussed. Content and data rates for communication from each

location are considered [11]. A recommended communications configuration is presented for each data path with costs and technical and operational considerations.

Six data paths are discussed. In all cases, data flow to the communications and control processor at SDAC. The six origin sites are: NORSAR, Iran, Korea, Site II, ALPA and LASA. The proposed communication configuration is summarized in Figure 2. This figure shows the similarity between the various sites.

At each of the six sites there is an interface between the data source and the ARPANET. This interface appears as a mini-host to the ARPANET and looks like a standard modem to the data source. In this report such a minihost will be referred to as a private line interface or PLI since existing data source equipment designed to interface with private leased lines need not be modified for use with the ARPANET. Development of a similar interface for another application has already begun at BBN. Five of the minihosts use Very Distant Host (VDH) protocol to communicate with a remote IMP. Four of these can be similar except for possibly minor variations due to different data rates, message sizes and message time constraints. The fifth minihost does not implement VDH protocol, but is not very different from the others. At the sixth site (LASA) the PDP-7 will be interfaced to the ARPANET as a Very Distant Host. Variation among the field sites will be handled for the most part by the CCP at SDAC (see section 4.4).

We assume that satellite links are used from Iran, Site II, Korea, and NORSAR, and that modems for satellite and terrestrial links will be furnished by the pertinent carrier, if possible. ARPANET communications charges are figured at \$.10 per  $10^6$  bits throughout.

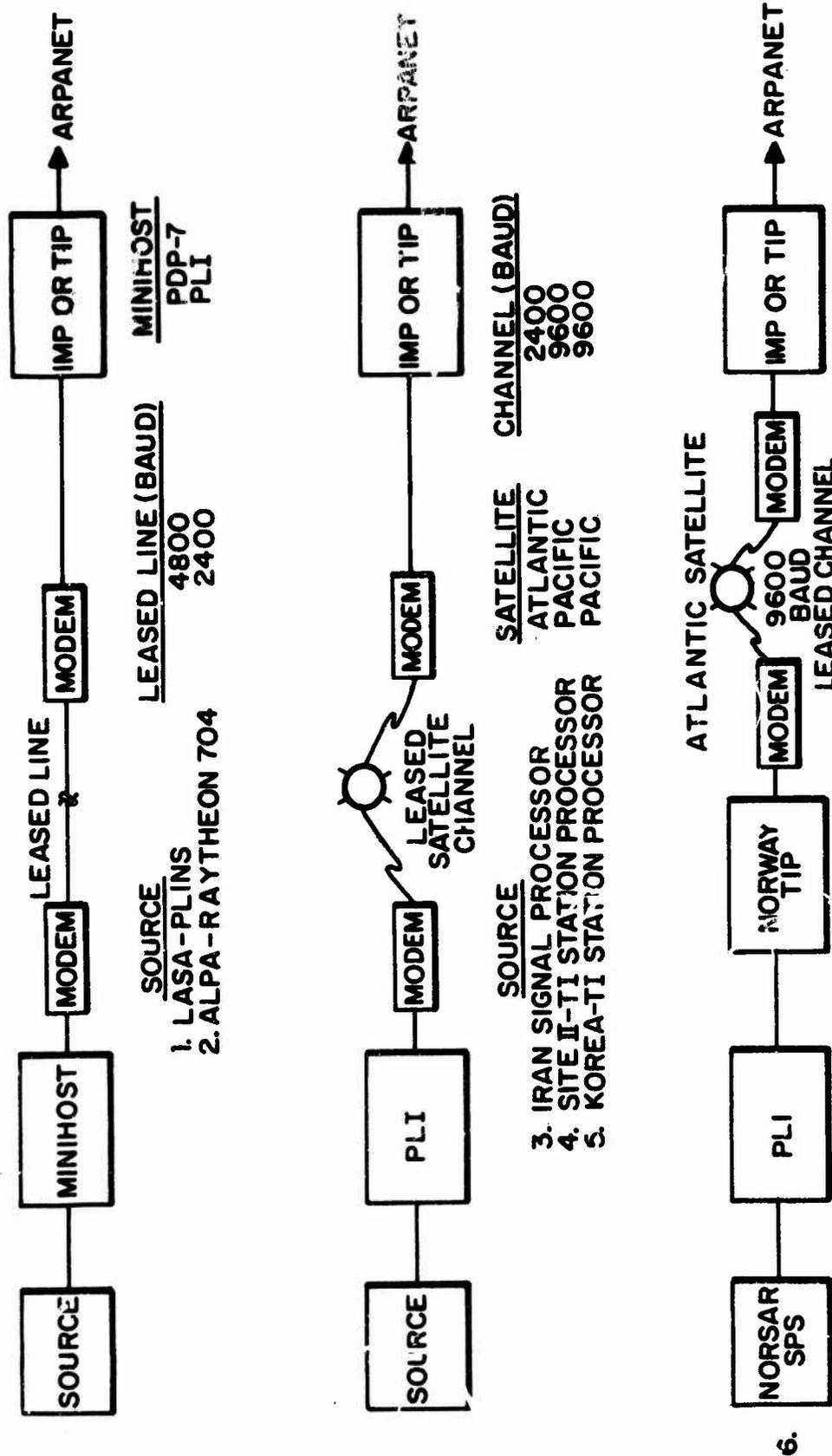


Figure 2 Data Acquisition

## A. NORSAR

1. Description

This site will have 22 three-component LP instruments and 132 SP instruments. The signal processor will continue to be an IBM 360/40, using the SPS front-end. The data will consist of all long period data, selected sensor and processed short period data, event descriptions and array status information. Total data rate will be 2400 bps, returned to the SDAC control computer and thence to a permanent storage site and/or a processing site.

A private line interface (PLI) minicomputer will be interposed between the SPS and the Norway TIP. The PLI will be programmed to accept data in the format of the SPS and to transform it to the valid Host-IMP format. The PLI will connect to the TIP as a local Host and will maintain a Host-Host connection with the SDAC control computer. The seismic data will be returned to the U.S. with other ARPANET traffic via a leased satellite channel.\*

The reverse link could be implemented in a similar manner with the PLI to interface with the NORSAR SPS, and a program in the CCP to transmit data peeled off of any of the site input streams or data from tape (or possibly to control transmission from tape on the 360/44) in the appropriate format.

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\* With this configuration the data rate could easily be increased up to 4800 bps in order to send more data. At 4800 bps the logic for communication between the NORSAR, DP and SPS would be the rate-limiting factor.

## 2. Costs

The major incremental cost is that of the PLI, approximately \$30,000, including installation. In-country maintenance costs for the PLI have yet to be negotiated. The cost of transmitting the data via the ARPA Network would be about \$7,500 per year.

## 3. Schedule

About six months ARO would be required to develop and install the PLI for the Norway site.

## B. Iran

### 1. Description

This site has more unknowns than any other. While the sensor configuration of seven three-component LP instruments is understood, the means of communicating this data to the signal processor is not clearly defined. The site processing and recording configuration is not yet selected. The data rate of about 340 bps will probably be best handled via a 2400 bps voice-grade satellite channel. However, the availability of a communications path between the signal processor site and the satellite ground station is in question and COMSAT has recommended installing a UHF microwave link. A tariff is not defined for any portion of the link to the U.S. although an estimated cost for the satellite portion has been obtained.

In light of the relatively isolated nature of the site, a paucity of trained personnel and communications facilities, and the fact that a "cheap" IMP may not be available in time, it is probably not cost-effective to plan for an IMP in Iran. Instead,

to provide error detection and retransmission, a PLI will be developed and installed. The PLI-IMP interface will operate over the 2400 bps channel using Very Distant Host (VDH) protocol. The channel will be connected to an IMP or TIP near the U.S.-side earth station which has an available Host slot (possibly the SDAC TIP). Data will be addressed by the Iran PLI to the CCP at SDAC. The PLI will be programmed to communicate with the Iran signal processor in its special format. Seismic data will then be packetized and entered into the ARPA Network via the VDH interface. The PLI will maintain a Host-Host logical connection with the control computer at SDAC. The PLI should be located near the array signal processor to reduce the complexity of the electrical interference.

## 2. Costs

A major incremental cost will be caused by the design, programming and installation of the PLI minicomputer. The estimated cost is \$35,000 installed, including a VDH interface at the IMP. Maintenance costs for a computer in a foreign country are indeterminate at this time. While there may be similarities to the NORSAR PLI, new software will have to be developed for the VDH and the interface to the Iran signal processor. Modem purchase costs should not exceed \$5000.

The Iranian PT&T has estimated a cost of \$180,000 per year for the 2400 bps satellite link via the Atlantic Intelsat IV to Tehran. It is presently unclear what the PT&T will charge for a 2400 bps circuit to the earth station. Since the U.S. Army STRATCOM is paying \$240,000 per year for a satellite circuit to the U.S. of only slightly more capability, it is difficult to make up the apparent discrepancy of \$60,000 per year in terms of circuit costs in Iran.

Data transmission costs within the ARPA Network will be about \$1100 per year. Modem and circuit costs from the earth station at Etam to the nearest IMP (in the Washington, D.C. area) would be about \$4000 per year.

### 3. Schedule

The PLI minicomputer can be installed within six or seven months after receipt of order. This time will be influenced strongly by two factors: availability of the signal processor for testing prior to installation and field tests; and the state of the seismic message format definition during design and programming of the PLI.

### 4. Problems

Acquisition of reliable data communications facilities from the PLI site to the earth station poses the most serious problem. Power source reliability, alluded to in the COMSAT survey, may have a long-term impact on the reliability of both the PLI and the signal processor.

### 5. Evolution

If the Iranians are afforded ARPA Network access via the eventual installation of a SIMP, the seismic data may be easily entered by connection to the PLI device already installed.

## C. Korea and Site II

### 1. Description

These sites are discussed together because their signal processors and data formats will be identical. Both sites will have seven three-component LP instruments and 19 vertical SP

instruments. The data returned will consist of all LP data and selected SP data. The total data rate will be 4800 bps from each site. The signal processor for the sites is manufactured by Texas Instruments. The data format design is complete. Site power, simple maintenance capability, and attending personnel are generally expected to be good.

The present schedule is to return data from these sites by 9/74 (Korea) and 3/75 (Site II). It is probably not feasible to install a "cheap IMP" within that period. Therefore, to gain error control, a VDH PLI minicomputer, similar to the device described for Iran should be installed near the TI signal processor at each site. Using conventional land lines to the earth stations and hops via the Pacific Intelsat IV to the Western U.S. coast, the seismic data will be entered at nearby IMPs with available Host ports. It will be necessary to lease ground and satellite channels greater than 4800 bps due to the VDH protocol overhead.

## 2. Costs

The PLI minicomputer and VDH interface at the IMP probably will not exceed \$35,000 for each site. In-country modems, if purchased, should cost no more than \$10,000. These might be leased from the local communication carriers as a part of the terrestrial circuit tariff. However, these costs are not known. The cost of the satellite channel is about \$180,000 per year per site. Costs of ground circuits from the U.S. earth station to the nearest IMPs should not exceed \$7000 per year per site. It will cost about \$15,000 per year to transmit the seismic data from each site via the ARPA Network to the SDAC control computer.

### 3. Schedule

The development and installation of the PLI for Sites II and Korea is dependent on the availability of the TI processor for interface testing. Also, while some of the PLI programming (VDH protocol) for the Iran site will be applicable to Site II and Korea, the interface to the processor may be different. Since the Iran site has a much lower data rate, basic software differences may develop in the PLI which make a parallel development effort impossible. In light of all this, it is estimated that it will take less than nine months to develop and install the PLIs at both sites.

#### D. LASA

##### 1. Description

The current plan for LASA reconfiguration calls for LASA to be scaled down to the equivalent of 14 single element short period sensors, and 9 three-element long period sensors. The total data rate from these channels will be approximately 2500 bps. Since this quantity of data would need to be sent to SDAC for event processing even if DP were moved to LDC, there is no reason to consider doing local (at the array) detection processing.

Data from LASA should be entered into the ARPA Network for transmission to SDAC. The PDP-7 located at the LDC will put the data onto the network at the nearest available IMP or TIP (e.g., the University of Utah) using VDH protocol. A 4800 bps leased line will be required between the array and the IMP.

## 2. Costs

The price of VDH hardware for the PDP-7 will be about \$10,000. VDH software for the PDP-7 would be part of the major PDP-7 software development required for the reconfigured LASA. The purchase of a modem interface for the IMP to accommodate the VDH connection costs about \$5K. Yearly operating costs for the circuit, assuming a 4800 baud, 400 mile link from Billings to Salt Lake City, ARPANET transmission costs, and service on the purchased equipment, come to approximately \$15K per year. This cost can be compared with the figure of \$14,000 which is the approximate cost of leasing a 4800 baud channel between Billings, Montana and Alexandria, Va. Since the 50Kb service from Billings to SDAC currently costs approximately \$125k/yr., the net yearly operating savings will be about \$110,000 on this communications link.

## 3. ALPA

### 1. Description

The ALPA site presently has 19 three-component LP instruments. The signal processor is a Raytheon 704, which sends a data stream to SDAC of 912 bps over a 2400 bps circuit.

The 1975 system will consist of the present configuration plus a PLI minicomputer operating via a VDH connection to the nearest IMP. The IMP may, of course, be either in Alaska or in the contiguous U.S. The expected initial configuration consists of a leased 2400 bps circuit to an IMP having an available Host port. If no IMP is installed in Alaska, the nearest one would probably be in the San Francisco area.

## 2. Costs

The acquisition, development and installation costs of the PLI device for ALPA will be approximately \$35,000, including the VDH IMP interface. Ground circuit costs to an IMP in the San Francisco area will be about \$35,000 per year, assuming there is no Alaskan IMP. The ARPANET transmission cost for a 1000 bps data stream will be about \$4000 per year. The present 2400 baud link from ALPA direct to Alexandria costs \$48,000 per year.

## 3. Schedule

As with the other sites, a six or seven month delivery should be anticipated for the PLI device. However, since the only major difference between this PLI and others (i.e., those for Iran, Korea and Site II) will be the data rate and format, there is likely to be a great deal of overlap, resulting in a shorter delivery time.

### 4.4 Communication and Control Processor

In order to provide the required flexibility in formats and protocol used for communicating between the field sites and the processing and storage facilities without having a separate one-of-a-kind interface processor for each site, we recommend a central communication and control processor (CCP) as a common termination point for communication with all sites. The primary functions of this processor would be 1) to provide a common destination Host for data arriving from all sites, both ARPANET and leased lines, 2) to distribute the information arriving from the sites to one or more appropriate Hosts for storage or processing, 3) to provide control for the file system, 4) to monitor and accumulate data on the operational status of the sensor

systems, communication circuits, and processing and storage facilities, and to interface with the network operator responsible for initiating maintenance and backup procedures, and 5) to provide the interface between the short period event processing operation and the rest of the system. Since SDAC will be responsible for the network operation and event processing, the CCP should be located at the SDAC. The five functions for the CCP are explained in more detail below.

1) Data arriving from different sites over the ARPANET will have different message formats, basic word lengths, path delays and rates (buffer requirements). Other sites may communicate over leased lines with various data rates. The destinations for the data may vary with time. For example, the archival storage may be at CCA for some period, then move to Ames. Some data may logically have two destinations (e.g., SP waveform data should go both to the event processing facility and to the archival storage facility).

The control and communication processor would be interfaced to the ARPANET at the SDAC TIP and would serve as the destination Host for all data transmitted from the sites, thus insulating the sites from changes in storage and processing facilities. An additional advantage of a single common Host destination is that a special Host protocol that can recognize the continuous real-time nature of the data flow can be defined for communication with the sites. The CCP could also be interfaced to leased lines for communication with some sites and would provide the buffer needed to accumulate logical blocks of data for entry into the ARPANET to communicate with processing and storage facilities.

2) The data transmitted from various sites contain different forms of information and parts of the information from a given site will have different logical destinations. The CCP will put all data of a common type (e.g., LP data) into a common format, may group similar data from different sites into blocks of common source time, and will forward the data to the appropriate ARPANET Host or Hosts. The coordinate transformations required for some of the LP data can also be considered a reformatting structure

3) The CCP will issue Datalanguage commands to enter seismic data into the Datacomputer system and to establish the desired indexes and directories. Changes in site configurations or instruments and addition or deletion of sites in the network require changes in the file structure. Using a terminal on the CCP, the network operator will be able to control the file structure when necessary.

4) Some of the network stations, such as LASA and NORSAR, may include sensor monitoring and sensor operational status in data transmitted from the site. Most of the communication formats include error detection mechanisms such as checksums. Additional communication system status and Host facility status information is available from the ARPANET. The operational status of the seismic network, as indicated by all of these sources and possibly by direct observation of the data, would be monitored by the CCP. Records for the file storage system describing the operational status of the network will be assembled and sent to the archival storage. The network operator terminal will be used to alert the operator to detected trouble in sensor systems, communications, or primary processing and storage facilities. Based on this information, the network operator may take such

actions as calling appropriate maintenance personnel and activating backup procedures such as local recording of data at the sites or at SDAC. He may be able to activate computer controlled diagnostic procedures to help determine the appropriate maintenance and backup procedures.

5) If the CCP, LASA DP and network event processing are collocated at SDAC as recommended here, there are at least several options related to how these three SDAC processors can be interfaced (see Figure 3).

In Option 1, neither the LASA DP system nor the network event processing system would be interfaced directly on the ARPANET. Input for the LASA DP system would be accumulated by the CCP and recorded on tape or disk (tape is assumed in Figure 3a). This tape would be carried to the 360/40A system for DP when necessary. Input to the network event processor would be accumulated by the CCP in a similar fashion on tape or disk (also shown as tape in Figure 3a) for all sites other than LASA. The LASA input to event processing would continue to be transmitted to EP via a shared disk. The major advantage of this configuration is its similarity to the current operation. Disadvantages of the decoupled system are that (1) network processing status cannot be monitored by the CCP, and (2) considerable tape movement may be necessary.

The arrangement described as Option 2 is shown in Figure 3b. In this case both the 360/40A and the 36/40B systems are interfaced as Hosts on the ARPANET; no tapes are involved. LASA DP data are forwarded to the 360/40A system by the CCP. DP outputs from sites other than LASA are also forwarded by the CCP to the

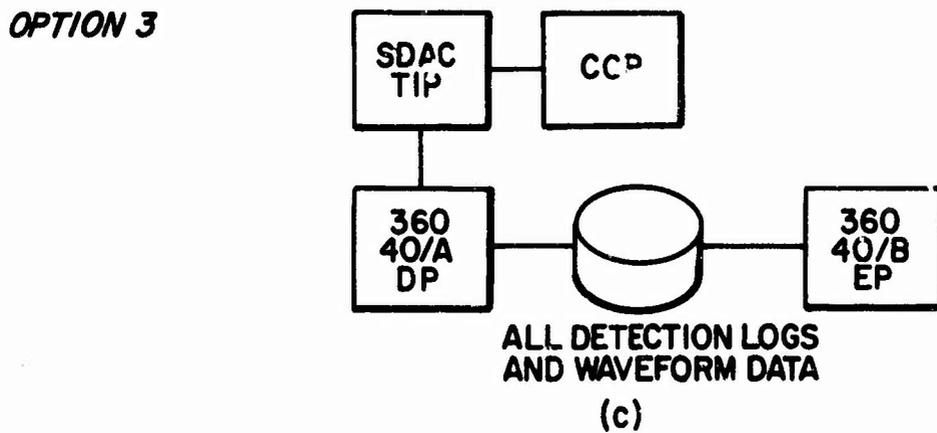
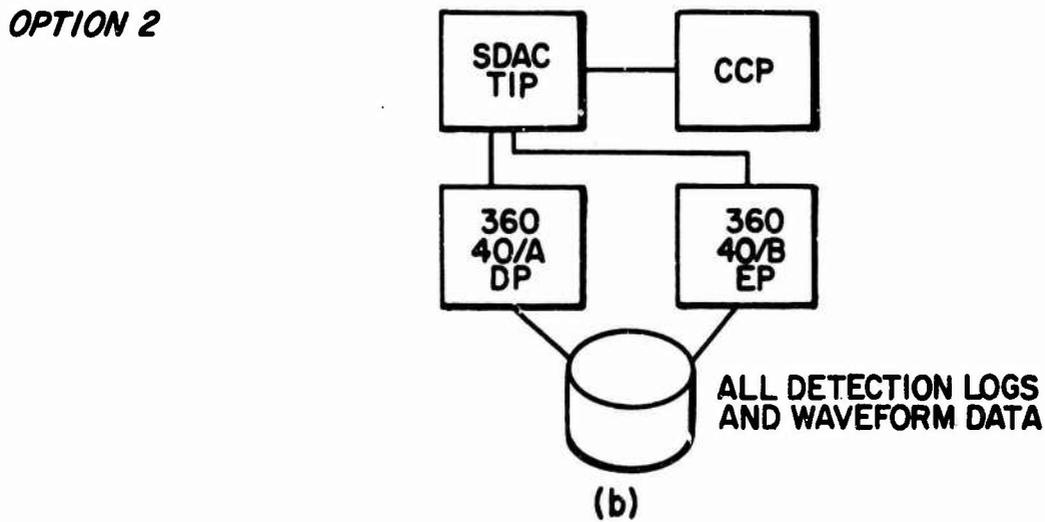
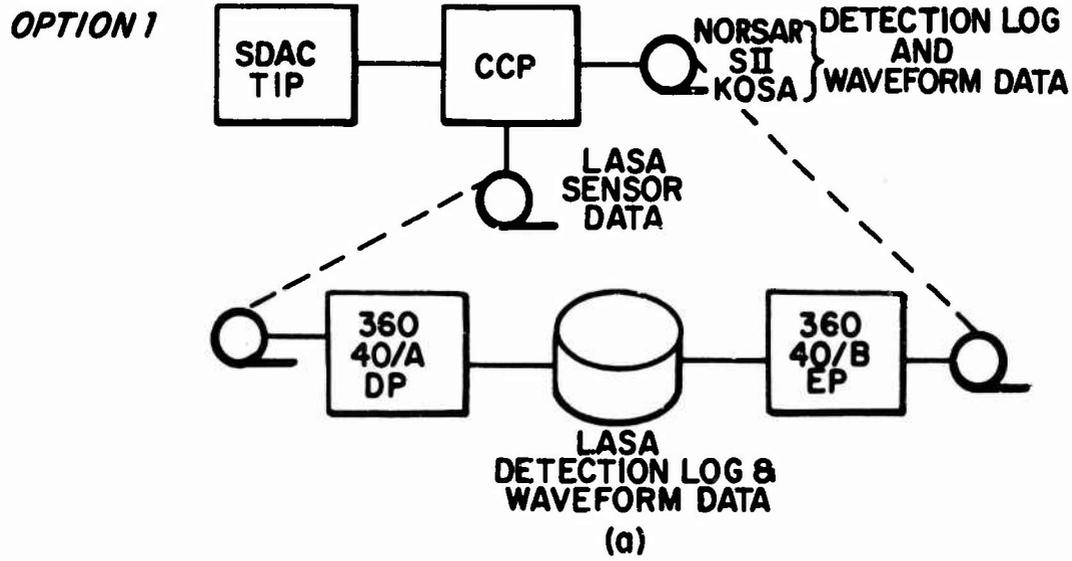


Figure 3 SDAC Options

360/40A system which queues this information on the disk unit shared by the 40A and 40B computers. LASADP output is also queued here. Option 2 has the advantage that EP processing system status can be monitored by the CCP. A serious problem, however, is that this would require more Host ports in the SDAC TIP than exist (in addition to the 3 shown in Figure 3b, there is the 360/44 and possibly the VDH interface for Iran). Only 3 Host ports exist on a TIP. Possible ways around this problem include having SDAC resources connected as Very Distant Hosts to other IMPs or adding another TIP or IMP at SDAC.

A third possibility is shown in Figure 3c as Option 3. This is a combination of Options 1 and 2 with the 360/40A DP system interfaced on the ARPANET. The DP output from NORSAR, KOSA, and Site II is queued as in Option 2 on the disk by the 360/40A. In order to allow the 360/40B computer to back up the primary on-line operation, it would be desirable to be able to switch the ARPANET Host interface from the 360/40A computer to the 360/40B computer. The Iran VDH would be interfaced to another TIP or IMP in the Washington, D.C. area in this case.

Aside from the five primary functions already discussed, the CCP may perform some additional tasks. One such task is the on-line LP processing (e.g., beamforming) currently being performed on LASA and ALPA data.

The equipment configuration for the CCP would consist of a two processor bus-oriented mini-computer system with 64K of memory. A system using magnetic tape to provide backup and using the ARPANET (option 2 or 3) as the mode of communication with the DP and EP systems at SDAC would cost on the order of \$100K for hardware. It would be desirable to use a graphic display terminal for the operator's console to permit examination of waveform data. Such a console will cost about \$20K. Software

development for the functions listed above would cost on the order of \$150K for a total cost of about \$270K. The second processor does not appear absolutely necessary for the 1975 system, but the cost for the second processor is under \$5K and the increased reliability and flexibility is worth this small cost. The software should be designed assuming a multiprocessor system in either case to insure easy system expansion if more sites are added to the network. The major hardware cost is in the required memory for communication buffer space and peripheral devices for network backup. Use of a single separate computer system for all control and communication tasks rather than breaking these functions up among other processors provides an extremely flexible system for accommodating future changes in site configurations, processing and storage facilities, communications, and the number of sites in the network.

The hardware delivery time for the CCP is likely to be on the order of 6 months. If software development can start before equipment delivery, the total delivery time for the system would be 9 months to a year.

#### 4.5 Event List Computation

##### 4.5.1 Short Period Data Processing

The ISRSPS short period data processing system has been operational for several years. Both DP and EP are performed at SDAC for LASA and at NDPC for NORSAR. Although this operation has been successful, planned changes to the LASA array and the expansion of the worldwide seismic network to include additional arrays necessitate reconsideration of the overall design for short period signal processing.

Available information indicates that the LASA configuration will be reduced substantially in size. In particular, the E and F subarray rings will be eliminated entirely and the remaining subarrays will have beams hardwired into them. The net effect of these changes is that LASA will appear as a 13 (short period) sensor array that is 50 km across. In addition, LASA will have a single low gain short period sensor for detecting large events and 9 three-component long period sensors.

In section 4.3 it was pointed out that sensor data would continue to flow from LDC to SDAC for the reconfigured LASA but at a much reduced rate. This data could enter the detection processor either via the CCP or directly over the ARPA Network. The former is probably preferable since this leaves backup recording in the hands of the CCP rather than the detection processor.

It would be reasonable to form several hundred beams from the 13 short period channels. In particular, there are at least two options related to beam deployment that make sense. First, one could continue to maintain two partitions, a general surveillance partition and a selected surveillance partition. In the general surveillance partition, the 299 array beams currently generated would be produced from the 9 subarrays (channels) in the A0 through C rings. These beams would cover the teleseismic zone. The 13 channels corresponding to subarrays in the A0 through D rings could be used to produce beams in the selected surveillance partition. A second approach to beam deployment would only form the general partition above during detection processing. Channels from subarrays in the D ring of LASA would be used only for best beamforming during event processing.

The most reasonable choice for a system on which to do detection processing is the 360/40A system at SDAC on which DP is currently being performed. Since there is no longer any subarray beamforming to do and the load due to filtering will be significantly reduced, the IBM Special Processing System (SPS) can be removed entirely from the short period detection processing system (communication functions are picked up by the CCP--see Section 4.4). This will have the positive effect of improving the overall maintainability of the system. In addition, there would be no hardware modifications required for this reconfiguration of the LASA DP system except the previously mentioned items related to communications. The development cost to modify the existing DP software may be significant but must be considerably less than the cost of developing the DP system from scratch on another machine. A figure of \$50K-\$100K would be reasonable to expect here with a 6-12 month delivery time.

While the DP load at SDAC may decline, the EP load at SDAC will definitely increase. The reason for this is the addition of new short period array sites (Site II and KOSA) and the fact that network event processing will be done centrally rather than independently at each of the array locations. In addition, short period data on tape from the SRO stations will be handled at SDAC (see Section 4.5.3). The choice of SDAC as a center for network event processing is a natural one since all of the network data will be routed there for distribution and there exists at SDAC considerable technical expertise with a working EP system.

One would expect the 360/40B event processing system to become saturated as the new load materializes. The precise configuration for network event processing will become clear only after more experience in this area has been accumulated. It makes sense, therefore, to rely on ARPA Network resources to service any event processing load that cannot be handled by the already purchased SDAC hardware. When the routine event processing load has been established, the purchase of additional computational hardware may be appropriate. The one piece of hardware which may need to be acquired sooner is a replacement for the Experimental Operators Console (EOC). The EOC provides a means for analyst interaction during event processing. Unfortunately, because of the one-of-a-kind nature of this device, parts and maintenance are a serious and costly problem. Rather than invest any significant amount of money in the EOC, it would be appropriate to consider the acquisition of a new interactive graphics facility to use for EP. The hardware for such a device would cost on the order of \$50,000.

#### 4.5.2 Long Period Data Processing

Current emphasis in the area of long period data processing has been on algorithm development and experimentation. Routine processing of long period data has not yet materialized for the sites already in existence. Because of this and the fact that a considerable amount of additional long period data will soon become available, the major new computational load on the 1975 seismic network will result from LP processing. The precise computer requirements to handle this load, however, are not clear at this point. These requirements will be determined largely by the system developed for routine long period processing.

In light of the existing uncertainties, it seems inappropriate at present to commit the seismic community to a particular hardware configuration for long period processing. A prudent approach would be to continue to access resources as needed over the ARPA Network. In the short run, the SDAC 360/44 and UCLA 360/91 can be used. Over the long haul, the ILLIAC IV at NASA Ames appears a desirable site at which LP processing can be done.

Long period data processing appears well suited to parallel execution on the ILLIAC IV array. In addition, since the computations need not be carried out in real time, the current mode of ILLIAC IV operation, namely remote batch without a guaranteed service level, is acceptable. Consider, for example, the f-k analysis algorithm described as FKCOMB [12]. The input to the algorithm is a number of channels equal to three times the number of LP (3-component) instruments (e.g., 27 channels for LASA). Each of these channels has to have its data edited. Following this, the FFT computation is performed for each channel. With the ILLIAC IV, PEs could perform calculation for the individual channels simultaneously. A three-dimensional power spectrum is then computed. For each of a specified set of frequencies  $f_1$ ,  $P(f_1, k_x, k_y)$  is computed for particular values of  $k_x$  and  $k_y$ . Maxima in  $f, k_x, k_y$  space are located by first locating maxima in two dimensions for the particular choices of  $f_1$ . Using the ILLIAC IV, each PE could be associated with a particular  $f_1$  and the above calculation could proceed in parallel. The channel filtering process referred to as "stripping" which permits secondary maxima to be located is also suitable for parallel execution.

The above discussion provides a feasibility argument for use of the ILLIAC IV. A more detailed evaluation of the suitability of the ILLIAC IV for long period data processing is called for. Such a study should (1) implement existing algorithms on the ILLIAC IV system, and (2) analyze in detail the relative merits of ILLIAC IV as opposed to other computers (e.g., 360/91) with regard to carrying out these algorithms. The study would have the positive side-effect of developing some general expertise in use of the ILLIAC IV for array signal processing.

#### 4.5.3 Processing of SRO/LPE Data

Magnetic tape containing SRO and LPE data will continue to arrive at NOAA in Albuquerque, New Mexico for data verification. As NOAA is not yet on the ARPANET, entry of data into the seismic subnetwork will be accomplished after forwarding the tapes to SDAC by mail. When and if NOAA Albuquerque becomes a node on the ARPA Network, it would make sense for NOAA to enter the data directly.

The processing of long period data (SRO and LPE) should be carried out using the 360/44 at SDAC. Short period data processing could also be accomplished at SDAC. This would consist of event processing in the neighborhood of previously detected events and would be accomplished on the 360/40s. It appears that the load on the 360/40A system due to the reconfiguration of LASA may leave sufficient capacity (CPU and storage) for SRO processing. If this is not the case, the 360/40B could be used. One could decide to do detection and event processing using all of the SRO sensor data; however, this would considerably increase the necessary computation for only a small gain in system performance.

#### 4.6 File Storage and Retrieval

With the system configuration described here, the data available for archival storage include 1) all raw LP data, 2) selected short period channels of sensor or beam data, 3) processed long period waveforms and 4) event list and residual unassociated detection logs.

In addition to the data discussed above, we suggest that whenever tapes of the SP raw data from any site for a selected event are requested by any user, the requested data should be entered into the file system.

The event list in the file system should have a list of the stations used to locate the event and of the stations used for computing  $M_s$  and  $m_b$ , in addition to the data in the current format of the LASA station bulletin.

Each block of waveform data in the file system should have an associated field for notes concerning the operational status of the sensors. This field would be used to note, for example, sensors with reversed polarity, out of calibration, inoperative, etc. For processed waveforms it may include magnification or notes on status of input sensors used.

The choice of what archived data should remain on-line can, and probably will, be changed from time to time as interest in the data or the availability of storage changes.

Historically, an important part of the VELA program has been development and deployment of appropriate instrumentation to collect the data needed for the signal analysis program. The subject network is one step in this process. There is no

reason to believe this activity will not continue. The definition of the data entered into the file system, therefore, should be expected to change with time. The responsibility for defining file content and format, and a mechanism for making changes, should be established at the beginning so that the file system does not become obsolete or chaotic.

Under ARPA sponsorship CCA is developing a file management system, called the Datacomputer system (see Section 3.2.4), for use as a service on the ARPANET. Through use of a protocol, the Datalanguage, designed for interaction between the Datacomputer and user computer programs, the Datacomputer system will allow flexible file structure and file indexing to be controlled by the source computer or by a third party computer. The initial version of the system is in operation at CCA, and a version of the system will be available at the Center for Advanced Computation at Ames. Both the CCA and the Ames facilities will be accessible via the ARPANET. The system at Ames will have access to the UNICON laser memory for a tertiary store. The system at CCA does not currently include tertiary storage, but one will probably be added as soon as demand justifies the expense.

Use of the Datacomputer system as the seismic data management system has three advantages: 1) it provides a very sophisticated data management facility to the seismic network without the software development cost, 2) it allows the choice of either the facility at CCA or Ames to be made and changed relatively easily depending on the operational status, available capacity, and processing facility in use, and 3) the ARPANET allows wide access to the data and remote control of the file definition and access.

Control of the file structure for the seismic data collected by the network should be and, using the ARPANET, can be under control of a responsible seismologic laboratory. Since SDAC will have responsibility for network operation and event processing, it seems reasonable that SDAC should also be responsible for file control.

Once the data have been entered into the Datacomputer system, they can be readily accessed by anyone with access to the ARPANET. As the ARPANET expands to include overseas nodes such as those in Norway and England, the data file can become an international resource.

The using seismologist will normally want to access the system in one of two sequences. He may search the network event list to select a population of events with some particular characteristic and then use that set of events in his investigations. Alternatively, he may want to access waveform data for a particular time whether an event has been detected by the network or not. In the latter case, the user may know the time of interest at the particular station or he may start with an assumed source event for which he has a source time and location.

Groups such as SDAC and Lincoln Laboratory that make extensive use of the data base will want a set of computer programs to aid in accessing the Datacomputer system for seismic data. At a minimum this set of programs would include the following:

- 1) a routine that allows the user to specify ranges of values for various entries in the event list such as magnitudes, event times, locations, etc., and a search window in time, such as the year 1973. The routine would then search the event list and produce a file of event list data for those events in the search time that meet the specified criteria.

2) a program that would allow the user to specify the station and a time window. The program would determine what data were available in the databank for that station and time. If sensor data from an entire array are recorded and saved at the station for some interval during which users can request copies, and if requested data are entered into the databank, then this program should include recognition of the existence of the sensor data at the stations as well as data in the archival file. The output of this routine would be a list of available data at the station which has not been put in the archival file and a list of data in the file. The list would include information necessary to request retrieval of the data such as tape numbers, file record numbers, etc.

3) a program to accept source time and location and a list of sites from the user, and to generate the expected arrival times of commonly observed phases at each of the sites.

4) a program to take data file access information from the second program (above) and to retrieve the data by producing a file at the user's facility, by recording a magnetic tape of the data to be mailed to the user, or by producing a file at some other facility such as an ARPANET server Host where the user will perform some computation.

These programs to provide file retrieval operations in a language the user understands may be quite expensive for each of the more casual users of the data to prepare for himself. Since these programs will certainly be prepared for the primary users (SDAC and Lincoln Laboratory), it would require only a modest additional effort to write them in a form accessible over the ARPANET so

that all users would have a seismologist-oriented retrieval capability. The programs could conceivably be made a part of the CCP system which would always be on-line, but more likely would be available from some service Host in the network such as one of the existing TENEX systems. If the SDAC 360/44 system were made a service Host with Host protocols including TELNET and FTP, these programs could be made available there.

In addition to this basic set of seismic file retrieval programs, ARPA should consider the long-term advantages of making a basic package of seismic array processing programs available on the ARPANET. An easily accessible package with beamforming, filtering, correlation functions, etc. would save the cost of having each user write his own programs for all these functions.

Other files that should be generally available and would be used in the operations discussed above are files of instrument locations, measured time anomalies, and nominal instrument characteristics for each type of instrument in the system.

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